

Contents

Preface	xv
Preface to the First Edition	xix
1 Introduction to Bridge Engineering	1
1.1 <i>A Bridge Is Key Element in a Transportation System</i>	2
1.2 <i>Bridge Engineering in the United States</i>	2
1.2.1 Stone Arch Bridges	3
1.2.2 Wooden Bridges	4
1.2.3 Metal Truss Bridges	8
1.2.4 Suspension Bridges	10
1.2.5 Metal Arch Bridges	14
1.2.6 Reinforced Concrete Bridges	17
1.2.7 Girder Bridges	20
1.2.8 Closing Remarks	21
1.3 <i>Bridge Specifications</i>	21
1.4 <i>Implication of Bridge Failures on Practice</i>	24
1.4.1 Silver Bridge, Point Pleasant, West Virginia, December 15, 1967	25
1.4.2 I-5 and I-210 Interchange, San Fernando, California, February 9, 1971	26
1.4.3 Sunshine Skyway, Tampa Bay, Florida, May 9, 1980	29
1.4.4 Mianus River Bridge, Greenwich, Connecticut, June 28, 1983	30
1.4.5 Schoharie Creek Bridge, Amsterdam, New York, April 5, 1987	35
1.4.6 Cypress Viaduct, Loma Prieta Earthquake, October 17, 1989	37
1.5 <i>Failures during Construction</i>	39
1.6 <i>Bridge Engineer—Planner, Architect, Designer, Constructor, and Facility Manager</i>	39
References	41
Problems	42

2 Aesthetics and Bridge Types	45
2.1 <i>Introduction</i>	45
2.2 <i>Nature of the Structural Design Process</i>	45
2.2.1 Description and Justification	46
2.2.2 Public and Personal Knowledge	48
2.2.3 Regulation	49
2.2.4 Design Process	49
2.3 <i>Aesthetics in Bridge Design</i>	51
2.3.1 Definition of Aesthetics	52
2.3.2 Qualities of Aesthetic Design	53
2.3.3 Practical Guidelines for Medium- and Short-Span Bridges	67
2.3.4 Computer Modeling	83
2.3.5 Web References	83
2.3.6 Closing Remarks on Aesthetics	87
2.4 <i>Types of Bridges</i>	87
2.4.1 Main Structure below the Deck Line	88
2.4.2 Main Structure above the Deck Line	89
2.4.3 Main Structure Coincides with the Deck Line	94
2.4.4 Closing Remarks on Bridge Types	96
2.5 <i>Selection of Bridge Type</i>	96
2.5.1 Factors to Be Considered	96
2.5.2 Bridge Types Used for Different Span Lengths	101
2.5.3 Closing Remarks on Selection of Bridge Types	108
References	109
Problems	111
3 General Design Considerations	113
3.1 <i>Introduction</i>	113
3.2 <i>Development of Design Procedures</i>	114
3.2.1 Allowable Stress Design	114
3.2.2 Variability of Loads	116
3.2.3 Shortcomings of Allowable Stress Design	117
3.2.4 Load and Resistance Factor Design	117
3.3 <i>Design Limit States</i>	118
3.3.1 General	118
3.3.2 Service Limit State	122
3.3.3 Fatigue and Fracture Limit State	124
3.3.4 Strength Limit State	125
3.3.5 Extreme Event Limit State	126
3.4 <i>Principles of Probabilistic Design</i>	127
3.4.1 Frequency Distribution and Mean Value	128
3.4.2 Standard Deviation	129
3.4.3 Probability Density Functions	129

3.4.4 Bias Factor	132
3.4.5 Coefficient of Variation	133
3.4.6 Probability of Failure	134
3.4.7 Safety Index β	136
3.5 <i>Calibration of LRFD Code</i>	141
3.5.1 Overview of the Calibration Process	141
3.5.2 Calibration Using Reliability Theory	142
3.5.3 Calibration by Fitting with ASD	152
3.6 <i>Geometric Design Considerations</i>	153
3.6.1 Roadway Widths	154
3.6.2 Vertical Clearances	156
3.6.3 Interchanges	156
3.7 <i>Closing Remarks</i>	157
References	158
Problems	159

4 Loads 161

4.1 <i>Introduction</i>	161
4.2 <i>Gravity Loads</i>	162
4.2.1 Permanent Loads	162
4.2.2 Transient Loads	164
4.3 <i>Lateral Loads</i>	189
4.3.1 Fluid Forces	189
4.3.2 Seismic Loads	189
4.3.3 Ice Forces	204
4.4 <i>Forces due to Deformations</i>	216
4.4.1 Temperature	216
4.4.2 Creep and Shrinkage	219
4.4.3 Settlement	220
4.5 <i>Collision Loads</i>	220
4.5.1 Vessel Collision	220
4.5.2 Rail Collision	220
4.5.3 Vehicle Collision	220
4.6 <i>Summary</i>	221
References	221
Problems	223

5 Influence Functions and Girder-Line Analysis 225

5.1 <i>Introduction</i>	225
5.2 <i>Definition</i>	226
5.3 <i>Statically Determinate Beams</i>	228
5.3.1 Concentrated Loads	229
5.3.2 Uniform Loads	233

5.4	<i>Muller–Breslau Principle</i>	235
5.4.1	Betti's Theorem	235
5.4.2	Theory of Muller–Breslau Principle	236
5.4.3	Qualitative Influence Functions	240
5.5	<i>Statically Indeterminate Beams</i>	241
5.5.1	Integration of Influence Functions	248
5.5.2	Relationship between Influence Functions	250
5.5.3	Muller–Breslau Principle for End Moments	254
5.5.4	Automation by Matrix Structural Analysis	257
5.6	<i>Normalized Influence Functions</i>	259
5.7	<i>AASHTO Vehicle Loads</i>	259
5.8	<i>Influence Surfaces</i>	275
5.9	<i>Summary</i>	275
	<i>References</i>	276
	<i>Problems</i>	277
6	System Analysis	283
6.1	<i>Introduction</i>	283
6.2	<i>Safety of Methods</i>	288
6.2.1	Equilibrium for Safe Design	288
6.2.2	Stress Reversal and Residual Stress	291
6.2.3	Repetitive Overloads	295
6.2.4	Fatigue and Serviceability	302
6.3	<i>Gravity Load Analysis</i>	302
6.3.1	Slab–Girder Bridges	303
6.3.2	Slab Bridges	347
6.3.3	Slabs in Slab–Girder Bridges	354
6.3.4	Box-Girder Bridges	372
6.4	<i>Effects of Temperature, Shrinkage, and Prestress</i>	385
6.4.1	General	385
6.4.2	Prestressing	386
6.4.3	Temperature Effects	386
6.4.4	Shrinkage and Creep	395
6.5	<i>Lateral Load Analysis</i>	395
6.5.1	Wind Loads	395
6.5.2	Seismic Load Analysis	400
6.6	<i>Summary</i>	408
	<i>References</i>	409
7	Concrete Bridges	411
7.1	<i>Introduction</i>	411
7.2	<i>Reinforced and Prestressed Concrete Material Response</i>	412

7.3	<i>Constituents of Fresh Concrete</i>	414
7.4	<i>Properties of Hardened Concrete</i>	417
7.4.1	Short-Term Properties of Concrete	418
7.4.2	Long-Term Properties of Concrete	430
7.5	<i>Properties of Steel Reinforcement</i>	440
7.5.1	Nonprestressed Steel Reinforcement	441
7.5.2	Prestressing Steel	448
7.6	<i>Limit States</i>	449
7.6.1	Service Limit State	449
7.6.2	Fatigue Limit State	454
7.6.3	Strength Limit State	461
7.6.4	Extreme Event Limit State	463
7.7	<i>Flexural Strength of Reinforced Concrete Members</i>	463
7.7.1	Depth to Neutral Axis for Beams with Bonded Tendons	463
7.7.2	Depth to Neutral Axis for Beams with Unbonded Tendons	468
7.7.3	Nominal Flexural Strength	471
7.7.4	Ductility and Maximum Tensile Reinforcement	476
7.7.5	Minimum Tensile Reinforcement	481
7.7.6	Loss of Prestress	482
7.8	<i>Shear Strength of Reinforced Concrete Members</i>	504
7.8.1	Variable-Angle Truss Model	506
7.8.2	Modified Compression Field Theory	510
7.8.3	Shear Design Using Modified Compression Field Theory	523
7.9	<i>Concrete Barrier Strength</i>	534
7.9.1	Strength of Uniform Thickness Barrier Wall	535
7.9.2	Strength of Variable Thickness Barrier Wall	540
7.9.3	Crash Testing of Barriers	540
7.10	<i>Example Problems</i>	540
7.10.1	Concrete Deck Design	541
7.10.2	Solid Slab Bridge Design	579
7.10.3	T-Beam Bridge Design	597
7.10.4	Prestressed Girder Bridge	636
	<i>References</i>	680
	<i>Problems</i>	683

8 Steel Bridges 687

8.1	<i>Introduction</i>	687
8.2	<i>Material Properties</i>	688
8.2.1	Steelmaking Process: Traditional	688
8.2.2	Steelmaking Process: Mini Mills	689
8.2.3	Steelmaking Process: Environmental Considerations	690
8.2.4	Production of Finished Products	691

8.2.5 Residual Stresses	692
8.2.6 Heat Treatments	693
8.2.7 Classification of Structural Steels	694
8.2.8 Effects of Repeated Stress (Fatigue)	704
8.2.9 Brittle Fracture Considerations	707
8.3 <i>Limit States</i>	709
8.3.1 Service Limit State	710
8.3.2 Fatigue and Fracture Limit State	711
8.3.3 Strength Limit States	722
8.3.4 Extreme Event Limit State	724
8.4 <i>General Design Requirements</i>	725
8.4.1 Effective Length of Span	725
8.4.2 Dead-Load Camber	725
8.4.3 Minimum Thickness of Steel	725
8.4.4 Diaphragms and Cross Frames	725
8.4.5 Lateral Bracing	726
8.5 <i>Tension Members</i>	727
8.5.1 Types of Connections	727
8.5.2 Tensile Resistance	729
8.5.3 Strength of Connections for Tensile Members	735
8.6 <i>Compression Members</i>	735
8.6.1 Column Stability Concepts	736
8.6.2 Inelastic Buckling Concepts	740
8.6.3 Compressive Resistance	742
8.6.4 Connections for Compression Members	748
8.7 <i>I-Sections in Flexure</i>	748
8.7.1 General	749
8.7.2 Yield Moment and Plastic Moment	754
8.7.3 Stability Related to Flexural Resistance	772
8.7.4 Limit States	796
8.7.5 Summary of I-Sections in Flexure	801
8.7.6 Closing Remarks on I-Sections in Flexure	801
8.8 <i>Shear Resistance of I-Sections</i>	801
8.8.1 Beam Action Shear Resistance	806
8.8.2 Tension Field Action Shear Resistance	807
8.8.3 Combined Shear Resistance	811
8.8.4 Shear Resistance of Unstiffened Webs	813
8.9 <i>Shear Connectors</i>	816
8.9.1 Fatigue Limit State for Stud Connectors	816
8.9.2 Strength Limit State for Stud Connectors	819
8.10 <i>Stiffeners</i>	828
8.10.1 Transverse Intermediate Stiffeners	828
8.10.2 Bearing Stiffeners	836

8.11 <i>Example Problems</i>	840
8.11.1 Noncomposite Rolled Steel Beam Bridge	841
8.11.2 Composite Rolled Steel Beam Bridge	864
8.11.3 Multiple-Span Composite Steel Plate Girder Beam Bridge	885
<i>References</i>	976
Appendix A Influence Functions for Deck Analysis	981
Appendix B Metal Reinforcement Information	984
Appendix C Computer Software for LRFD of Bridges	987
Appendix D NCHRP 12-33 Project Team	988
Index	991